Applying Choosing-By-Advantage for Selecting Scheduling Technique in Elevated Urban Highway Projects

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ABSTRACT

The construction or rehabilitation of elevated highway projects presents a spectrum of challenges to project practitioners. These challenges place a demand on the multi-criteria decision making (MCDM) abilities of the project management team. Moreover, micro-scheduling of construction activities has been deemed important to the reduction of waste based on the lean paradigm due to the changing dynamics of the construction site. Choosing the project scheduling method that will facilitate value creation for the stakeholders becomes an MCDM problem and entails having a clear understanding of the advantages and disadvantages of the different scheduling methods under consideration. Choosing by Advantage (CBA) is an emerging lean construction MCDM method that has been successfully applied to the Architecture, Engineering and Construction (AEC) industry but with little application in infrastructure projects such as the construction of elevated urban highway projects. Decision makers using the CBA list the attributes and advantages of each alternative and then assign a degree of importance to each advantage relative to the one that is least preferred. The CBA helps to differentiate alternatives based on the decision context and reduces time to reach consensus. Furthermore, it manages better subjective trade-offs by basing decisions on the importance of agreed advantages. This study contributes to the body of knowledge by applying the CBA in the selection of the micro-scheduling method in elevated urban highway projects.

Keywords: Lean construction, Choosing-by-Advantage, Multi-criteria decision making, project schedule

INTRODUCTION

The need for new and reconstructed highways is an important consideration for many nations of the world as transportation developments shift from the construction of new highways to the demolition and reconstruction of existing facilities. A large number of reconstruction and rehabilitation work is expected on existing highways either due to existing highway infrastructure nearing or having already surpassed their service life (Jeannotte and Chandra 2005; Mahoney 2007) or due to the effect of urbanization placing additional demands on existing highways. Current practice in the construction industry suggests that there is typically budget overrun and schedule slippage during the construction of elevated urban highway projects (Dawood and Shah 2007; Hannon 2007). Addressing the challenge of ageing highways can be a difficult and sometimes contentious issue as there are many options and impacts to consider. To counter these challenges, a considerable amount of time is required to ensure that the level of development (LOD) of the plan can accommodate the micro-scheduling of short duration activities. However, selecting the project scheduling method becomes a multi-criteria decision-making problem because of the different project scheduling alternatives available to the project management team.

LITERATURE REVIEW

Decision-making methods influence how people make decision. These decisions trigger actions, which in turn have outcomes and consequences (Suhr 1999). During the construction of elevated urban highway projects, the decision of the project scheduling method to adopt is an MCDM problem and an important consideration in the delivery of the project. The problem, however, is that the literature does not provide much (if any) support to practitioners in this context. According to Arroyo (2014), in practice, decisions such as the planning and scheduling method to adopt are made without a formal method. She further contended that many practitioners responsible for decision-making are not even aware of the available MCDM methods.

Different MCDM methods are available in the literature and have been successfully applied in different fields. A literature review by Arroyo et al. (2014) revealed that most applications of MCDM within the construction industry are based on Weighting Rating Calculating (WRC) and the Analytical Hierarchical Process (AHP) (Aguado et al. 2011; Akadiri et al. 2013; Bakhoum and Brown 2011). The application of CBA has mainly been in the domain of research on lean construction (Arroyo et al. 2012, 2013; Nguyen et al. 2009; Parrish and Tommelein 2009).

CBA is a decision-making system that facilitates decision-making by comparing the advantages of alternatives (Arroyo et al. 2013). According to (Arroyo et al. 2015), the CBA system has four principles: (1) decision makers must learn and skillfully apply sound decision-making methods; (2) decisions must be based on the importance of the advantages; (3) decisions must be based on relevant facts; (4) different types of decisions call for different decision making methods. This method has several benefits over traditional MCDM methods: CBA helps to differentiate between alternatives based on the decision context, reduces time to reach consensus, and manages better subjective trade-offs by basing decisions on the importance of agreed advantages (Arroyo et al.

2018). Arroyo (2014) claimed that the decision-making process of CBA is more transparent than the AHP that utilises pairwise comparisons between factors to find the best alternative. CBA has been applied to choose the best design options for a reinforced-concrete beam column joint (Parrish and Tommelein 2009), a ceiling tile in the design stage from a sustainable perspective (Arroyo et al. 2013) , a structural system (Arroyo et al. 2014), a project team (Schottle et al. 2015), an HVAC system for a net-zero energy museum (Arroyo et al. 2016), select fall protection measures (Karakhan et al. 2016). Moreover, CBA was combined with a 4D model to select the best construction flow option in a residential building (Murguia and Brioso 2017). Table 1 presents a glossary of terms relevant to the CBA method (Suhr 1999).

Table 1: CBA definitions

Term	**Definition**
Alternatives	Options to be considered by the method. At least two alternatives are required for a decision to be necessary.
Factor	A property of an alternative that is material to the decision. Factors can be social or environmental but do not include the cost
Criterion	“Want” criterion defines a certain value or set of values that are preferred for a factor. “Must have” criterion specifies values that a factor must have for that alternative to be considered feasible.
Attribute	Quality or characteristics belonging to one alternative.
Advantage	Difference between two alternatives when their attributes are compared

In implementing the CBA method, the following steps adapted from Arroyo (Arroyo et al. 2015) are followed.

1. Identify the alternatives for consideration in the decision process.
2. Define the factors that will help differentiate among alternatives.
3. Define the *must* and *want* criteria for each factor.
4. Summarize the attributes of each alternative.
5. Decide the advantages of each alternative.
6. Decide the importance of each advantage (IofA). The IoA corresponds to a value that is given for each factor for each alternative. The sum of the IofA for all factors represents the total importance of that alternative to the decision maker.
7. Evaluate cost data (if applicable).

In CBA, decisions are based solely on the advantages. The stakeholders access the importance of these advantages by making comparisons among them. The weighing process should be based specifically on the importance of these advantages (Suhr 1999).

CBA ANALYSIS: SELECTING PROJECT SCHEDULING METHOD

Nine project managers involved in highway construction were chosen for the analysis and the steps for conducting the CBA were applied. Three different planning alternatives were identified in the literature. The Last Planner System (LPS), Critical Path

Method (CPM) and Linear Scheduling Method (LSM) were selected. Seven factors were jointly identified in an interactive session with the project managers that will serve as the basis for differentiating the alternatives. The "must" criterion for each factor on which the stakeholders will base their judgement alternatives was defined.

The attributes of each alternative were obtained from existing literature and validated by the project managers. The least desirable attribute for each identified factor is underlined and used as a comparison to describe the advantage of the alternative based on that factor. The advantage of each alternative was then decided by each respondent by assigning weights to the advantages based on the factors and criteria. The weights for each factor and criteria ranged from 0 to 100. The first author complied and obtained the average weight from the different weights provided by the respondents. The average weight so obtained was thereafter used as the relative weight for each advantage. The importance of each alternative (IofA) was then decided based on the relative weight earlier obtained. The IofA corresponds to the value given to the advantage of each alternative based on each factor by each respondent. The respondents collaboratively agreed on the IofA after some deliberations.

STEP BY STEP CBA APPLICATION

Step 1: Identify Alternatives. Three scheduling techniques were selected based on their suitability to linear projects. The alternatives considered are compared based on certain criteria and presented in Table 2.

Table 2: Project scheduling alternatives

		Alternatives		
Nos.	Factors	Last planner system	Critical path method	Linear scheduling method
1.	Reduction of uncertainty and risk	Identifies and assigns responsibility for constraints removal, facilitates reduction of risks and uncertainties.	Does not focus on identification of constraints and their removal. Makes up for this by incorporating float and slack (or modified PERT) in the schedule to account for production and duration uncertainties.	Does not tackle detailed task-level planning or identification of constraints which could have an impact on risks and uncertainties.
2.	A better understanding of project objectives	Breaking production into smaller and manageable flows ensure that project objectives are fully understood by stakeholders.	CPM networks become complicated as the size and complexity of a project increases.	Easy to use and facilitates an understanding of project objectives due to the relationship of time and space inherent in the process.
3.	Ease of use/implementation in linear projects	Easy to use. However, the absence of computer tools makes it cumbersome to apply to large work packages.	Extensive computerization has made the CPM easy to use. However, the user needs a considerable amount to produce valuable information for controlling purposes.	Very intuitive and easy to use and understand. However, limited computerization tools make it difficult to use in a large and complex project.
4.	Resource management	Address resource availability during the	Addressing key resource availability is a shortfall of this method. It focuses	Does not explicitly consider resource management. Resource levelling

		"Making-ready" process by matching workflow to capacity	on calculating the theoretical early start and finish dates, late start and finish dates for all scheduled activities.	is difficult as it lacks resource levelling capabilities.
5.	Collaboration and communication	A collaborative planning process that facilitates communication in the form of consultations at all stages of the project	Reduced collaboration and communication between stakeholders.	Provides a graphical display of how crews and equipment move through the project over time and therefore facilitates communication and collaboration.
6.	Space planning	The process of "making ready" focuses on the identification and removal of constraints and helps ensure that space-time relationships are considered but does not visualize them.	Does not consider time-space relationships during the planning process	Easy to visualize project schedule to account for time and space constraints. Facilitates space planning.

Step 2: Define Factors. Factors that will help the stakeholders differentiate between alternatives were identified. Several factors were considered, and the relevant factors were chosen for the decision-making process (Figure 1). Factors having the same purpose were combined due to their close relationship (e.g. easy to use and implementation in linear projects). Such merging helps to avoid double counting.

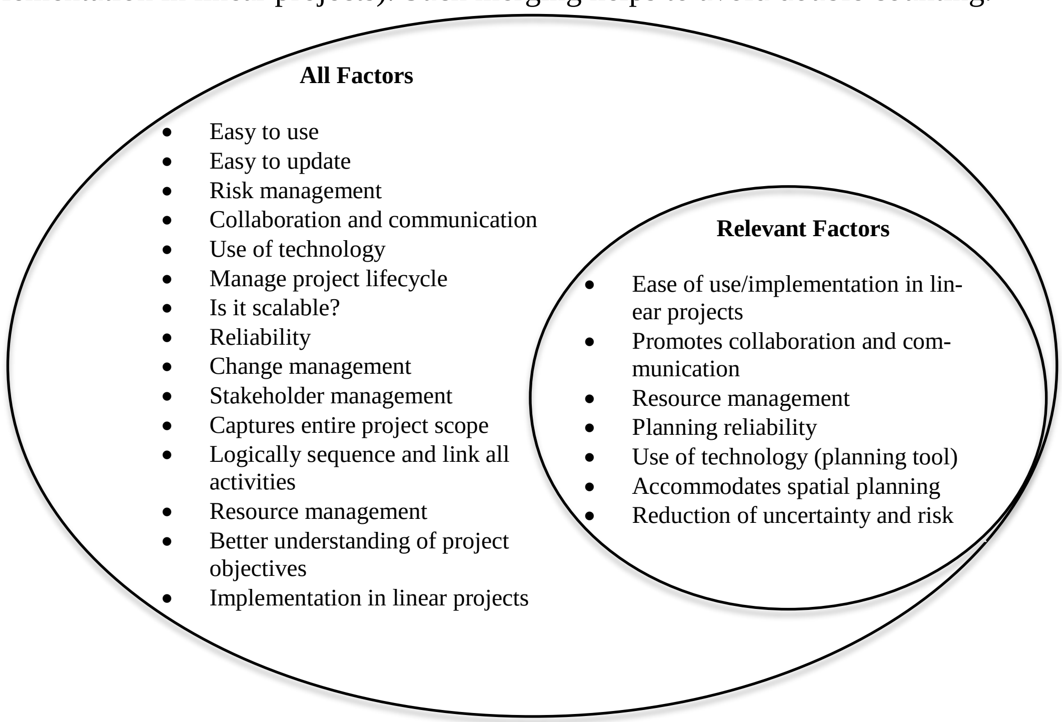

Figure 1: Identified factors for decision making

Step 3: Define the "must" and "want" criteria for each factor. The project managers agreed on the criteria upon which to base their decision making, and then weights were assigned collaboratively. In some cases, the stakeholders did not arrive at a consensus weight for some of the criteria, in this case, the arithmetic mean was obtained, and this was collectively accepted. For example, factor 1 considered the "ease of use/implementation in linear projects". The stakeholders agreed that the criterion for this factor is "Easier is better" and collectively agreed to ascribe a weight of 50 to this criterion. Column 1 of Table 3 shows the relevant factors used for the CBA analysis, the "must criterion" for each factor and the weight of the criterion.

Step 4: Summarise the attributes of each criterion. The main attribute of each alternative with respect to each factor is summarised. The least preferred attributes are summarised and underlined to highlight them. This provides the basis for comparison between alternatives in describing the advantages of one alternative over another.

Step 5: Decide the advantages of each alternative. The main advantage of each alternative based on a given factor and attribute is determined and shown in italic. For each factor, the least preferred alternative will not have an advantage.

Step 6: Decide the importance of each advantage. This is done collaboratively and decisions on what weight to ascribe to each advantage are agreed upon. The maximum advantage that can be ascribed to each advantage depends on the weight given to the factor, the values range from 20 to 100. The most important advantage for each factor is agreed upon by all stakeholders as a first step to assigning it the maximum agreed weight. Thereafter, depending on the number of alternatives, the stakeholders next agree on the weight to assign to the second "best" alternative. For instance, in factor 2: "promotes collaboration and communication", the stakeholders could not reach a consensus on the weight to assign to the second-best alternative. The first author who facilitated the CBA session resolved this impasse by taking the arithmetic mean of the different weights proposed by the different participants and this was adopted as the consensus value for the second-best alternative. The importance of advantage (IofA) for each alternative is summed up at the end of the session and the alternative with the highest IofA value is selected as the most preferred.

Step 7: Evaluate cost data if applicable. This step was ignored as there is no cost data associated with the choice of alternatives. However, if cost data exists, it is evaluated by plotting the IofA score for each alternative against the cost of selecting an alternative.

The summary of the CBA analysis is presented in Table 3.

Table 3: CBA Implementation

Factor & Criterion	Last Planner System		Critical Path Method		Linear Scheduling	
1. Ease of use/ implementation in linear projects **Crit.:** Easier is better **Max. Weight**: 50	**Attr.:** Easy to use and based on operational planning		**Attr.:** Convoluted in complex projects, and ineffective for linear continuous projects		**Attr.:** Used in linear projects where the majority of the work is made up of highly repetitive activities	
	Adv.: understand the presence of variability in production, human-focused	**IofA** 35	**Adv.:** None	**IofA** 0	**Adv.:** *Performs optimally when applied to linear projects*	**IofA** 50
2. Promotes collaboration and communication during the project execution phase **Crit.:** Higher is better **Max. Weight**: 100	**Attr.:** Planning is done mainly at the project level and is therefore flexible		**Attr.:** Planning is rigid, and process focused and carried out on a strategic level		**Attr.:** Planning is carried out on a strategic level and best implemented as an effective management tool at field level	
	Adv.: *More collaboration and communication during the execution stage*	**IofA** 100	**Adv.:** None	**IofA** 0	**Adv:** Collaboration and communication during the execution stage	**IofA** 60
3. Resource management **Crit.:** Higher is better **Max. Weight**: 50	**Attr.:** The process of "making ready" and constraint removal are tools in resource management		**Attr.:** Integrated with Network planning tools		**Attr.:** Does not explicitly consider resource management.	
	Adv.: Enhanced collaboration and communication promotes resource management	**IofA** 20	**Adv.:** *Facilitates resource allocation, levelling and smoothing*	**IofA** 50	**Adv.:** None	**IofA** 0
4. Plan reliability **Crit.:** Higher is better **Max. Weight**: 25	**Attr.:** Planning is done in detail closer to the task execution		**Attr.:** Planning is comprehensive with long term focus		**Attr.:** Easy to schedule continuity on linear projects, improving coordination and continuity	
	Adv.: *Commitment planning by the last planners increases planning reliability*	**IofA** 25	**Adv.:** None	**IofA** 0	**Adv.:** Improved coordination and continuity and visualization of the time-space relationship	**IofA** 15
5. Use of technology (planning tools) **Crit.:** Availability of technology is better **Max. Weight**: 50	**Attr.: S**imple and manual planning technique. Planning is carried out in the "big room" collaboratively using big plain boards and stickers.		**Attr.:** Well-advanced tools available for use, easily adapted to numerical computerization		**Attr.:** Intuitive and easy to understand but cannot easily be adapted to numerical computerization as readily as network methods	
	Adv.: None	**IofA** 0	**Adv.:** *Availability of technology supporting the implementation*	**IofA** 50	**Adv.:** Limited number of computerization implementation platforms	**IofA** 0
6. Ability to accommodate space planning **Crit.:** Ability to accommodate space planning is better **Max. Weight**: 100	**Attr.:** Pull-based scheduling that facilitates micro-scheduling. Focuses on "how" instead of "what"		**Attr.:** Focuses on "what" instead of "how". Emphasizes on the critical path		**Attr.:** Considers and accurately represents space-time relationships	
	Adv.: Constraint removal techniques facilitates space planning	**IofA** 50	**Adv.:** None	**IofA** 0	**Adv.:** *Facilitates the visualization of space-time relationships*	**IofA** 100
7. Reduction of uncertainty and risk **Crit.:** Higher is better **Max. Weight**: 50	**Attr.:** Produces a predictable and reliable workflow		**Attr.:** Complemented by EVM and PERT with statistical abilities.		**Attr.:** The ability to visualize time-space relationships provides some possibilities for risk reduction.	
	Adv.: Project percent complete (PPC) and Variance Analysis (VA) can be used to reduce uncertainty and risk	**IofA** 35	**Adv.:** *Statistical abilities help planners to get a better idea of time and schedule risk*	**IofA** 50	**Adv.:** None	**IofA** 0
Total IofA		*265*		**150**		**225**

The results of the CBA analysis show that during the construction of elevated urban highways, the LPS is preferable, subject to the selected factors and criteria. However, changing the factors and the criteria used in the analysis may lead to a different outcome for different types of project.

DISCUSSION

Several issues were identified in the implementation of CBA. These include: (1) Getting relevant stakeholders to gather in one room to make project decisions. To counter this, the project kick off meeting (KOM) can be used to greater effect. (2) Considerable time was dedicated to collecting data. Currently, no research work has compared the three scheduling method used in this analysis. Hence the factors upon which the attributes were defined, and the definition of the attributes took a lot of time. It is important to note that the data collection process is integral to any MCDM method. (3) The stakeholders used for the case study analysis had to be trained in the application of the CBA method, the method and vocabulary had to be explained and the commitment to training time may present a barrier to first-time users of the method.

CONCLUSION

CBA is an important decision-making method that integrates the perspective of multiple stakeholders. This study suggests the application of CBA in selecting the project scheduling technique to apply in the construction of elevated urban highway projects. The conclusions from the case study that may be generalized are: (1) CBA was helpful in integrating the perspective of multiple stakeholders. (2) CBA facilitated the identification of critical success factors necessary for selecting a suitable project scheduling method for highway projects. Some barriers were identified in the application of the CBA method. The most important barrier was the difficulty in getting the decision makers in one room at the time of decision.

It can be surmised that the application of CBA fosters more collaboration and exchange of ideas during the decision-making process, enhances transparency as decisions are made based on the importance of advantage of agreed factors.

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